Recent Top Properties Measurements at CDF

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Abstract. We present the most recent CDF results on the measurements of the decay and production vertex of the top-quark. New results on forward-backward asymmetry in top-antitop events are presented. Also, recent measurements of the branching fractions of top-quark are discussed. Finally, measurements in single top events, where top-quark is produced through electroweak processes, are presented. Despite the much larger number of top events collected at the LHC, due to the symmetric initial state and the better signal-to-background ratio in specific channels, some results will be lasting heritage of the Tevatron.

1. Introduction

Top quark was discovered at the Tevatron in 1994-1995. Since then its properties were extensively studied by the CDF and D0 experiments. The last Tevatron run (2001-2011) provided almost 10 fb^{-1} of data to each experiment. In this document I will concentrate on the most recent CDF results that exploit this wealth of data.

Thanks to its large mass, top is the only quark we can study before hadronization, therefore we have the unique opportunity to study a "bare" quark. From an experimental point of view, observables are (in most cases) perfectly well defined. The importance of this very peculiar quark cannot be underestimated. Its mass is strictly related, through loops, to the Higgs mass and to vacuum stability; its large Yukawa coupling is puzzingly close to one.

Top quark can be produced via electroweak mechanism (single top processes) or via strong interactions (in top-antitop pairs). Despite the very small signal/background ratio for single top production process, both Tevatron experiments detected (and studied) top quark in both cases. As top decays in a W and a quark (almost 100% of cases a b-quark), topologies of top-quark events are classified according to the charged boson decay. For strongly produced top events we call "dilepton" events in which both Ws decay leptonically, "l+jets" events in which one of the two Ws decays hadronically and "all-hadron" the case in which both bosons decay in quarks[1]. Therefore the typical physics objects present in a top-candidate event of interest are one or two charged leptons (e or μ), from 2 to 4 jets (two coming from b-quark hadronization), and large missing transverse energy signalling the presence of one or two neutrinos.

In the following analyses we use events with large (> 20 GeV) E_T electrons or muons, large (> 25 GeV) missing transverse energy (MET) and jets of hadrons (reconstructed by a fixed cone algorithm) with $E_T > 20$ GeV and pseudorapidity $|\eta| < 2.8$.

[1] In the following I will not present results related to the all-hadronic topology.

2. Study of top-quark properties in $t\bar{t}$ events

Top production vertex can be studied in top-antitop pair events and in events in which top-quark is produced singly. CDF studied all topologies and first measured production cross section. A summary of the Tevatron results for the top-pair production is shown in Figure 1. The final CDF result is $\sigma_{t\bar{t}} = 7.63 \pm 0.5$ pb, to be compared with the theoretical prediction of $7.35^{+0.11}_{-0.21}(scale)^{+0.17}_{-0.12}(PDF)$ pb. The Tevatron result is $\sigma_{t\bar{t}} = 7.6 \pm 0.41(stat)^{+0.2}_{-0.36}(syst.)$, and CDF contribution weights ≈ 60 % to the precision obtained with the combination.

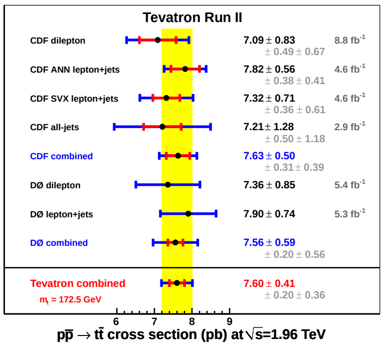

Figure 1. Measurements of $\sigma_{t\bar{t}}$.

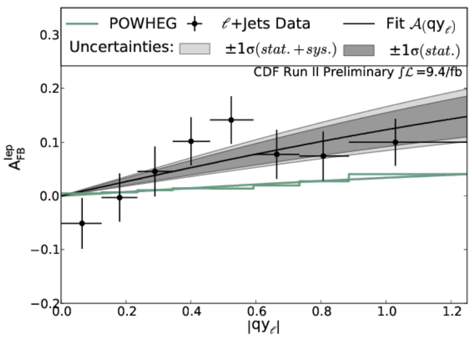

Figure 2. Fit to A_{FB} in l+jets data.

2.1. Angular distributions in $t\bar{t}$ events

CDF studied the distribution of the angle θ between the proton and the top direction in the $t\bar{t}$ reference frame looking for deviation from SM expectations. A description of $d\sigma/d\theta$ in terms of Legendre Polynomials shows that the first moment has some tension with the SM expected value (a difference at the 1.8 σ level), but there is not enough sensitivity to the other terms of the expansion to draw any conclusion.

Another important distribution to look at is the forward-backward asymmetry. Defined as $A_{FB} = (N_{\Delta Y>0} - N_{\Delta Y<0})/(N_{\Delta Y>0} + N_{\Delta Y<0})$, where ΔY is the difference in rapidity between top and antitop, this quantity is sensitive to new physics. Positive asymmetry is present in the production process which proceeds via $q\bar{q}$ annihilation at tree level or via a box diagram. Initial (ISR) and Final (FSR) state radiation can induce a negative asymmetry. Past CDF observation showed a tension with the SM with $A_{FB} = 0.066 \pm 0.02$ in the $l + jets$ channel. This value, brought back at the parton level, translates into an asymmetry of 16.4 ± 4.7 %, almost doubling the SM prediction [1].

This result prompted a number of studies. Here we present new measurements in the $l+$ jets and the dilepton channels and their combination.

The asymmetry in the $l + jets$ channel can also be studied in terms of direct observables, defining the leptonic asymmetry: $A^l_{FB} = (N_{q_l\eta_l>0} - N_{q_l\eta_l<0})/(N_{q_l\eta_l>0} + N_{q_l\eta_l>0})$, where l indicates the lepton. The final result is $A^l_{FB} = 9.32^{+3.2}_{-2.9}$ % against a SM expectation of 3.8 ± 0.3 %. Figure 2 shows the A^l_{FB} as a function of η [2]. This result shows again tension with the SM.

Recently CDF studied the leptonic asymmetry in the dilepton channel. This time one can separately study the symmetric and asymmetric part of the distribution of $q \times \eta$ and compare both to SM expectations. Figure 3 shows the distribution of $q \times \eta$ compared to POWHEG predictions, and Figure 4 the asymmetric part. The result, $A^l_{FB} = (7.2 \pm 5.2(stat) \pm 3(syst)) = (7.2 \pm 6.0)$ % is consistent with SM expectation of (3.8 ± 3) %. In order to improve the experiment sensitivity one can use both measurements to obtain the best estimate. Using 3864 events from the $l+jets$ channel (73% purity) and 569 from the dilepton channel (72% purity) , CDF combines

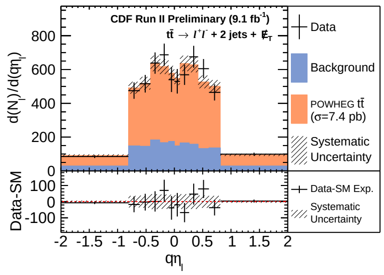

Figure 3. Distribution of $q \times \eta$ in dilepton events.

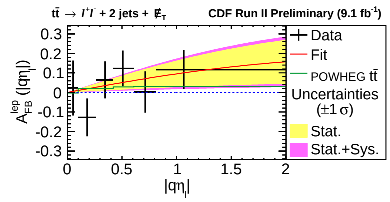

Figure 4. Asymmetric part of the $q \times \eta$ distribution compared to different theory predictions.

(using BLUE) the results and measures $A_{FB} = (9.0^{+2.8}_{-2.6})$ %. Figure 5 shows the CDF results compared to SM prediction. The final (combined) result is $\simeq 1.8\sigma$ away by the SM central value.

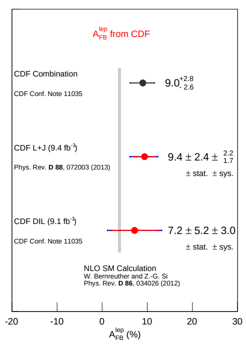

Figure 5. Summary of CDF results for A_{FB}.

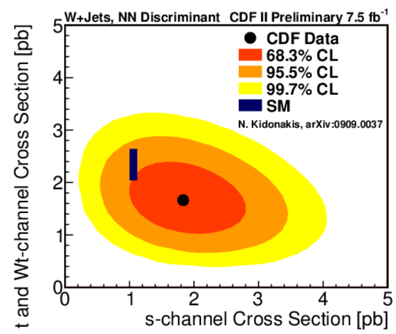

Figure 6. Simultaneous s and t cross section determination.

2.2. Indirect determination of the CKM element $|V_{tb}|$

The top-quark decay vertex is related to CKM matrix element V_{tb}. One can directly measure the branching fractions and there are two ways in which one can study V_{tb}: indirectly, via ratio of branching fractions, or directly, studying single top events.

In the SM, $\sum(|V_{td}|^2 + |V_{ts}|^2 + (|V_{tb}|^2) = 1$, therefore a measurement of the ratio of branching fractions $R = \frac{|V_{tb}|^2}{|V_{td}|^2+|V_{ts}|^2+|V_{tb}|^2}$ provides an estimate of $|V_{tb}|$.

From an experimental point of view, one proceeds by counting the number of top candidate events with 0,1,2 b-tagged jets, and comparing these figures with expectations as a function of R. Both CDF and D0 performed several measurements in this way. The most recent ones are due to CDF in the $l + jets$ and in the dilepton channels. In the l+jets by simultaneously fitting R and the $t\bar{t}$ production cross section, it measures $R = 0.94 \pm 0.09$ and $\sigma_{t\bar{t}} = 7.5 \pm 1.0$ pb, setting a 95 % C.L. limit of $|V_{tb}| > 0.89$ [3].

The strategy to extract R in the dilepton sample is different from the l+jets case as, thanks to the very good S/B ratio, it is possible to first extract the cross section, without using b-tagging techniques and then measure the b-content of the jets present in the events. Using an integrated luminosity of 8.7 fb^{-1} CDF measures $R = 0.87 \pm 0.07(stat + syst)$ [4] from which one extracts $|V_{tb}| = 0.93 \pm 0.04$ or $|V_{tb}| > 0.85$ at 95 % C.L. limit This result, together with the

the D0 result [5] in the dilepton channel ($R = 0.86 \pm 0.05$), is tantalizing away from the SM expectation.

3. Study of top properties in single top events

Single top production, is the generic definition that encompasses electroweak-produced events with only one top (or antitop) quark in the final state. Besides production through t or s channel (relevant at the Tevatron), single top-quark can also be produced in association with a W boson. Latter process is predicted to be negligible at the Tevatron, and evidence for its existence was recently obtained by CMS at the LHC.

Single top production is important, as its cross section is *directly* proportional to $|V_{tb}|^2$. Therefore it provides access to the $W-t-b$ vertex, probes the $V-A$ structure of the theory, gives access to the top spin and, of course, makes possible to directly measure $|V_{tb}|$ and explore possibilities of new physics. Besides, existence of FCNC currents or of heavy bosons, Kaluza Klein excitations, charged Higgs, may affect differently t and s channel. Although precision electroweak measurements rule out a fourth generation, there is still room for extensions [6]. Precise comparison of measurements of single top event properties, could open windows on New Physics (if any).

Single top production channels have final state topologies than can be mimicked by processes with much larger cross section. Indeed at the Tevatron, we are dealing with processes whose rate is smaller than the background fluctuations. In general, given a topology, we combine several channels, then we develop one (or more) Artificial Neural Network(s) (ANN) to identify the signal by fitting the appropriate distribution. CKM element is extracted by using the relation: $|V_{tb}|^2 = |V_{tb}^{SM}|^2 \times \frac{\sigma^{obs}}{\sigma^{SM}}$.

CDF recently submitted to PRL its result for the $s+t$ channel. Using 7.5 fb^{-1} we observe $\sigma_{s+t} = 3.04 \pm 0.55$ pb from which we extract $|V_{tb}| = 0.95 \pm 0.09(stat. + syst.) \pm 0.05(th.)$, and set a limit $|V_{tb}| > 0.78$ at 95 % C.L. Then, by simultaneously fitting s and t components[2], we extract $\sigma_{t+Wt} = 1.66^{+0.53}_{-0.47}$ pb and $\sigma_s = 1.81^{+0.63}_{-0.58}$ pb (see Figure 6), to be compared with SM prediction of $\sigma_{t+Wt} = 2.34 \pm 0.3$ pb, and $\sigma_s = 1.06 \pm 0.06$ pb [7]. If we combine this result with the previous analysis in the MET+$b\bar{b}$ channel, we set a limit $|V_{tb}| > 0.84$ at 95 % C.L.

Finally, as the s-channel is very difficult to observe at the LHC, both CDF and D0 optimized their selections to observe this mode of production. After this optimization, CDF re-analyzed its MET+$b\bar{b}$ and l+jets sample, also using a new b-tagger developed for the Higgs search. We find evidence for s-channel production at 4.2 σ, measuring $\sigma_s = 1.38^{+0.38}_{-0.37}$ pb [8]. By combining this result with D0 analysis, the Tevatron experiments reported the observation of the s channel production at 6.1 σ, measuring $\sigma_s = 1.29^{+0.26}_{-0.22}$ pb [9].

3.1. Acknowledgments

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[2] Wt component is included in the t channel as it shares the same final state topology.